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OILFREE LABYRINTH PISTON COMPRESSOR

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INTRODUCTION

Oilfree piston compressors are machines using no liquid lubricant in the parts through which process gas flows or is compressed. Normally, they are classified according to the types of sealing techniques applied for the reciprocating parts:

- Diaphragms.
Flat or rolling, metallic or non-metallic diaphragms seal the compression chambers
- Dry-running contact sealing elements.
Self-lubricating, low wearing, dry-running piston rings and gland elements replace the oil-lubricated piston rings and rod packings of conventional metallic design
- Contactless sealings.
Piston and glands are sealed by the labyrinth effect

The machines of the second and the third group have found the widest application because of their large capacity and pressure range. Whereas the dry-running, ring-sealed machines are directly derived from conventional lubricated designs, the application of labyrinth sealing techniques to reciprocating parts in compressors was an entirely new idea when it was first introduced in 1935 by Sulzer Bros. Ltd., Winterthur.

DESIGN OF OILFREE PISTON COMPRESSORS IN GENERAL

To a certain extent oilfree reciprocating compressors have to be designed in accordance with the same fundamental principles. The classical crank gear is the most appropriate means to actuate a reciprocating piston in a medium or large compressor. Since this is an oil-lubricated part, it

has to be separated efficiently from the dry cylinder; consequently, using the trunk piston design is almost impossible. The heavier and more expensive crank drive with a cross-head is therefore a typical feature of almost all oilfree piston compressors.

Usually the lubricated crank gear is separated from the dry cylinder by a distance piece. It is slightly longer than the stroke of the machine, arranged between a bulkhead in the frame, carrying the oil-scraper package, and the piston rod gland.

To achieve a very efficient oil removal, the piston rod should travel as accurately as possible in a line parallel to its axis. On one end it is guided by the cross-head which runs between machined and oil-lubricated surfaces. Guidance on the other end can be achieved by a machined and oil-lubricated guide bearing outside the cylinder or by a self-lubricated bearing in the cylinder. The latter solution requires a non-metallic bearing material that is exposed to the temperature and pressure of possibly contaminated gas. Self-lubricated bearing material, of course, wears out and has to be replaced.

DESIGN OF THE OILFREE SULZER LABYRINTH PISTON COMPRESSORS

The essential feature of the Sulzer labyrinth piston compressor is the contactless sealing between piston and cylinder wall and between piston rod and piston rod gland. Labyrinth seals require no lubrication and no abrasive products gain access to the process gas.

The design of this compressor type requires a very exact guidance of piston rod and piston. This is achieved on the lower end by the cross-head and on the upper end by the piston rod guide bearing outside the cylinder. Both guiding elements are pre-

cisely machined and hydrodynamically lubricated.

The Sulzer labyrinth piston compressor is vertically designed avoiding the slightest piston rod bending by the concentrated mass of the piston. For maintenance work, such as withdrawing piston and cross-head, no special tools are necessary. In addition, the vertical design eases the separation of the oil-lubricated crankcase from the oilfree cylinder; therefore no double compartment distance piece is considered for the Sulzer labyrinth piston compressor. As a rule, a vertical machine type requires less ground space than a horizontal unit.

The piston speed of labyrinth compressors is limited by the unbalanced forces and moments of inertia and by the oil scrapers. It is not influenced by increasing wear of self-lubricated materials. In fact, relatively high speeds are possible allowing a compact compressor design.

Depending on size and machine type, the crankcase may consist of a single frame or a combination of frame and base plate.

Directly coupled to the crankshaft is the oil pump, force-lubricating the crankshaft, connecting rod and cross-head bearings, the cross-head itself and, if existent, the crankshaft slip ring seal. The guide bearing is splash lubricated. The lubrication oil flows to the pump via an oil filter installed in the oil sump. The pump is equipped with an adjustable relief valve to limit the oil pressure during starting up with relatively cold oil.

The piston rod is a very delicate detail. It must be rigid. The surface in the dry part should be corrosion resistant. A perfectly smooth, accurate and hard rod surface is required where it travels through the scraper ring package. Nitrided steel has been chosen with upper part chromium plating.

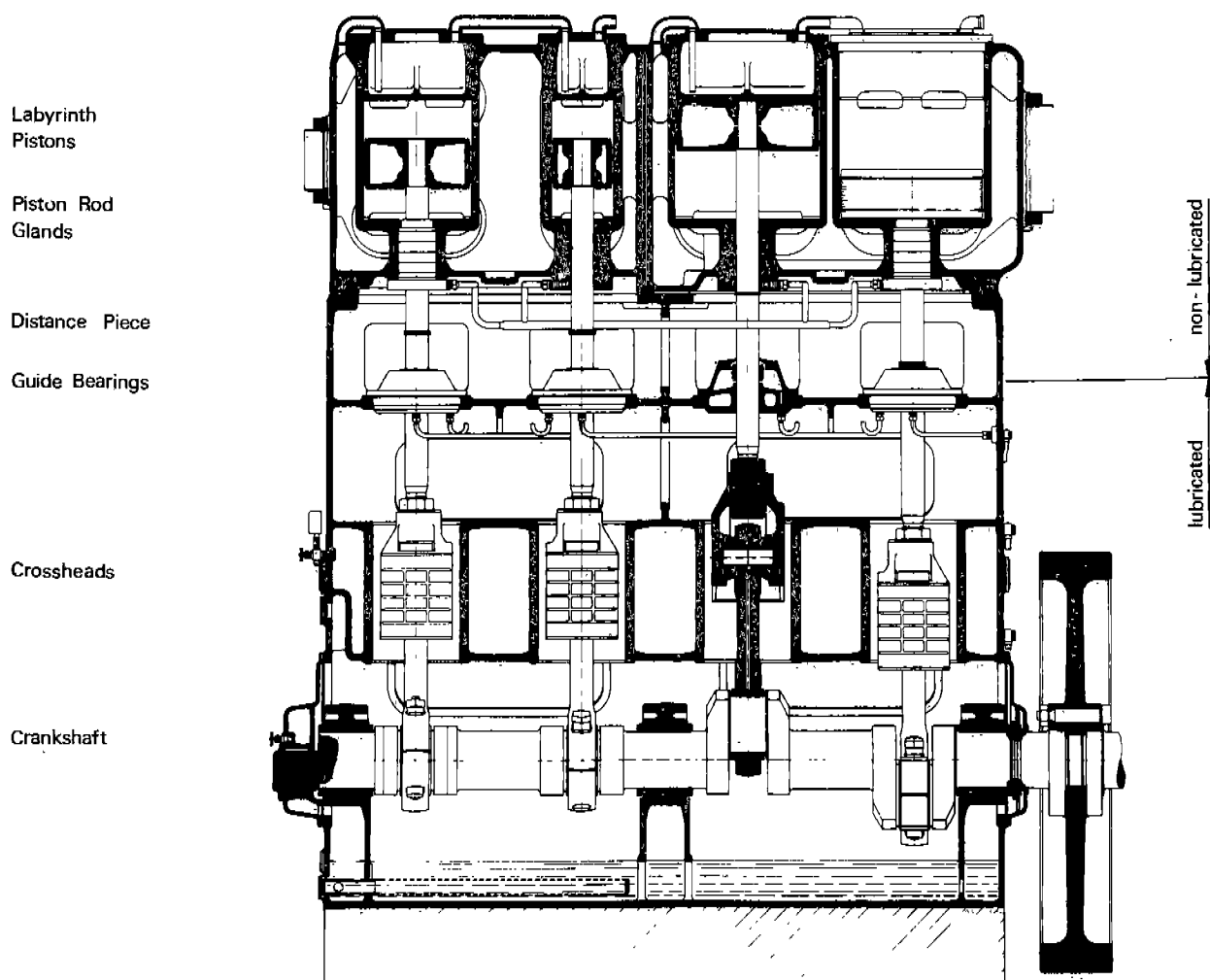


Fig.1 3-stage labyrinth piston compressor with open crankcase

A very important detail is the guide bearing (Fig.2) with the oil scraper package on top of it. The scraper rings (Fig.3) have to remove the oil from the surface of the piston rod. Although this can not be done perfectly, the remaining layer of oil on the piston rod must be sufficiently fine to slick on the rod rather than cluster in drops which would be heavy enough to be thrown towards the dry-running side. It is important that this fine oil film does not creep up the oscillating piston rod. Therefore, the dry upper part of the piston rod is separated by an oil shield. Other factors which are very important to the performance of the oil scrapers are the characteristic of the oil and the temperature

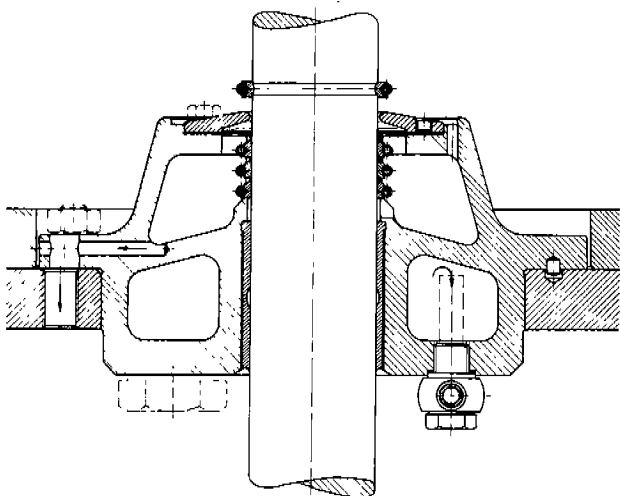


Fig. 2 Oil-lubricated and water-cooled piston rod guide bearing with oil scraper ring package

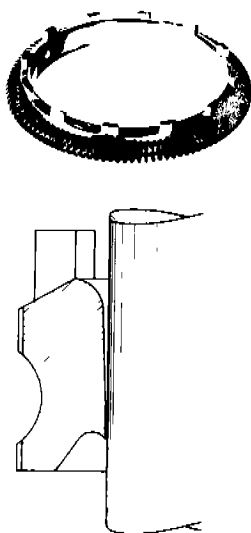


Fig. 3 Oil scraper ring of metallic design for reciprocating piston rod

of the local area, particularly of the piston rod surface. Cooling around the oil scrapers and of the piston rod surface achieved by the water cooled guide bearing shows excellent results by giving a better consistency of the oil film sticking to the rod.

The piston rod gland (Fig.4) has to seal between considerably different pressure levels. Labyrinth sealing using floating rings (Fig.5) has given the best results. The leaking gas is collected in a ring chamber at the lower end and piped back to suction or other acceptable pressure level or is vented to the atmosphere. Graphite, with a low thermal expansion coefficient and high chemical inertness is an almost ideal material for sealing rings. Although known for its increasing wear under extremely dry conditions, the results obtained with graphite labyrinth sealings are practically unaffected by the dew point of the gas, as no continuous positive contact to the piston rod occurs. The ideal thermal expansion coefficient of graphite results in practically equal clearance between seal ring and piston rod over a large temperature range. P.T.F.E. compound rings could by no means be of solid design.

A labyrinth gland leaks more than a contact piston rod packing. According to the nature of gas, pressures, size of cylinder, clearance, number of seal rings etc., gland leakage may amount from a fraction of one percent to a few percent of the mass flow through the cylinder. Where feasible, the leaking gas is vented back to the compressor intake and does not represent a real loss of process gas. The final gland leakage to the distance piece de-

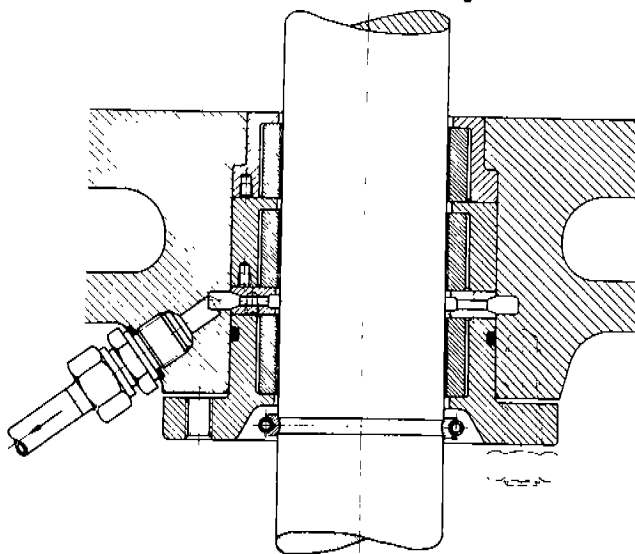


Fig. 4 Oil-lubricated and water-cooled piston rod guide bearing with oil scraper ring package

depends on the differential pressure between the suction and the pressure inside the distance piece and is normally negligible. If a reciprocating compressor is running with an elevated suction pressure, the gland leakage can be led back to the suction of a low pressure unit.

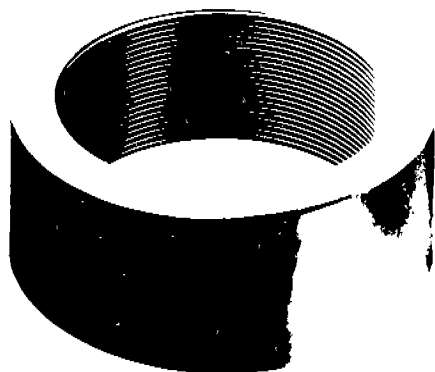


Fig 5 Floating labyrinth sealing element

Special attention has been given to the cylinder block design to obtain high heat-transfer from the gas in the cylinder to the cooling water. Except for very corrosive gases as chlorine, hydrochloride acid etc., cylinders are not equipped with dry cylinder liners. For a few high pressure compressors, mainly bottle filling machines, wet cylinder liners are a constructional necessity.

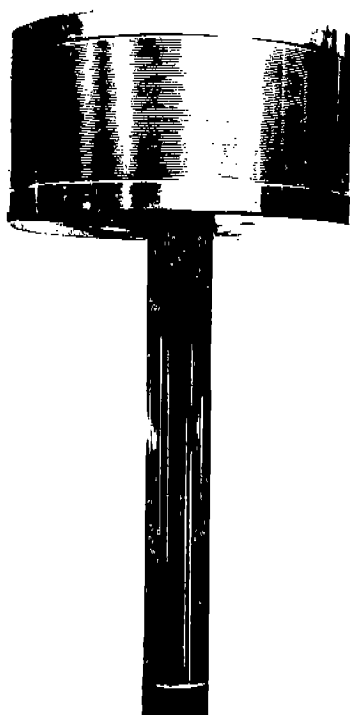


Fig. 6 Double acting labyrinth piston with upper part of piston rod

The labyrinth piston (Fig.6) is of a very light design. Where possible, the double acting piston consists of three parts, the upper and lower piston cover and the piston skirt. The material of the covers depends on the piston diameter and the process gas. It is made of nodular cast iron, steel or aluminum. Especially for oxygen the steel or iron covers are copper plated. The material of piston skirts as well as of single acting pistons depends on the process gas; it can be made of bronze, aluminum or cast iron.

The compressor valves (Fig.7) are of the plate valve type working without mechanical friction. Where possible, they are assembled horizontally into the compressor cylinder and therefore are easily accessible for maintenance work. Basically the same valve type is used on the suction and discharge side, but they are designed in such a way as to make it impossible to assemble a suction valve on the discharge side or vice versa.

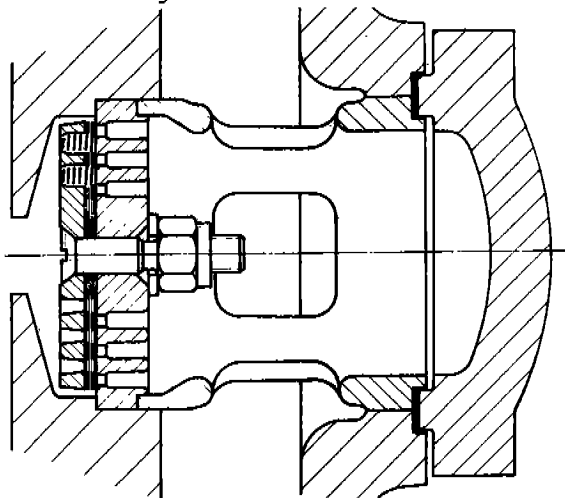


Fig. 7A Plate valve on suction side

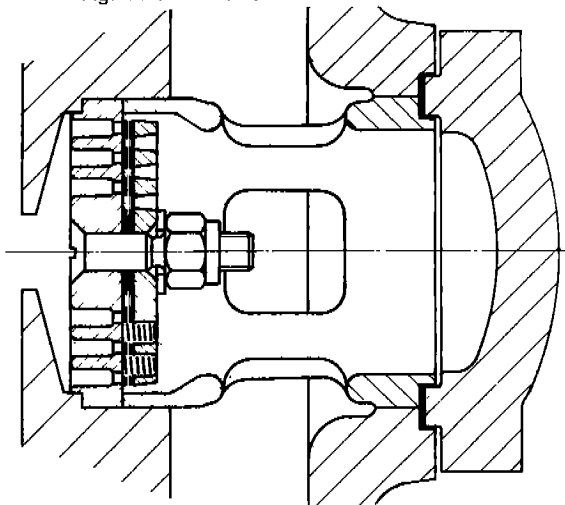


Fig. 7B Plate valve on discharge side

COMPRESSOR DESIGN WITH OPEN OR CLOSED CRANKCASE

The construction principles and the compressor elements described in the previous paragraph are used for two different kinds of compressors, the machine with an open ventilated distance piece and the machine equipped with a completely closed gas- and pressure-tight crankcase.

Compressor Design with Open Crankcase

Basically this compressor (Fig.8) was designed to compress non-toxic and more-or-less harmless gases such as air, oxygen, nitrogen, carbon dioxide etc. A complete separation of the dry cylinder part and the oil-lubricated crankcase is achieved by an open or ventilated distance piece.

Equipped with standard piston rod glands, the leakage gas is led back to the suction side of the first stage. According to the difference between suction pressure and the pressure inside the distance piece

a negligibly small amount of leakage gas flows between the piston rod gland lantern ring and the distance piece.

For specifically designed booster compressors a special piston rod gland is used. From an additional gland connection the remaining leakage gas is collected and led to a low pressure system, therefore, representing no real loss of process gas.

A further modification of piston rod gland and cylinder allows compression of chlorine, hydrochloride acid etc. with no leakage to the environment.

If the suction pressure is approximately atmospheric or slightly above, the crankcase of this machine type can be completely closed. Covers are used for the distance piece openings and a slip ring seal for the crankshaft. These alterations allow gases to be compressed with no admissible leakage to the environment. Large compressors for hydrogen, helium, hydro carbons, carbon monoxide etc. are of this design.

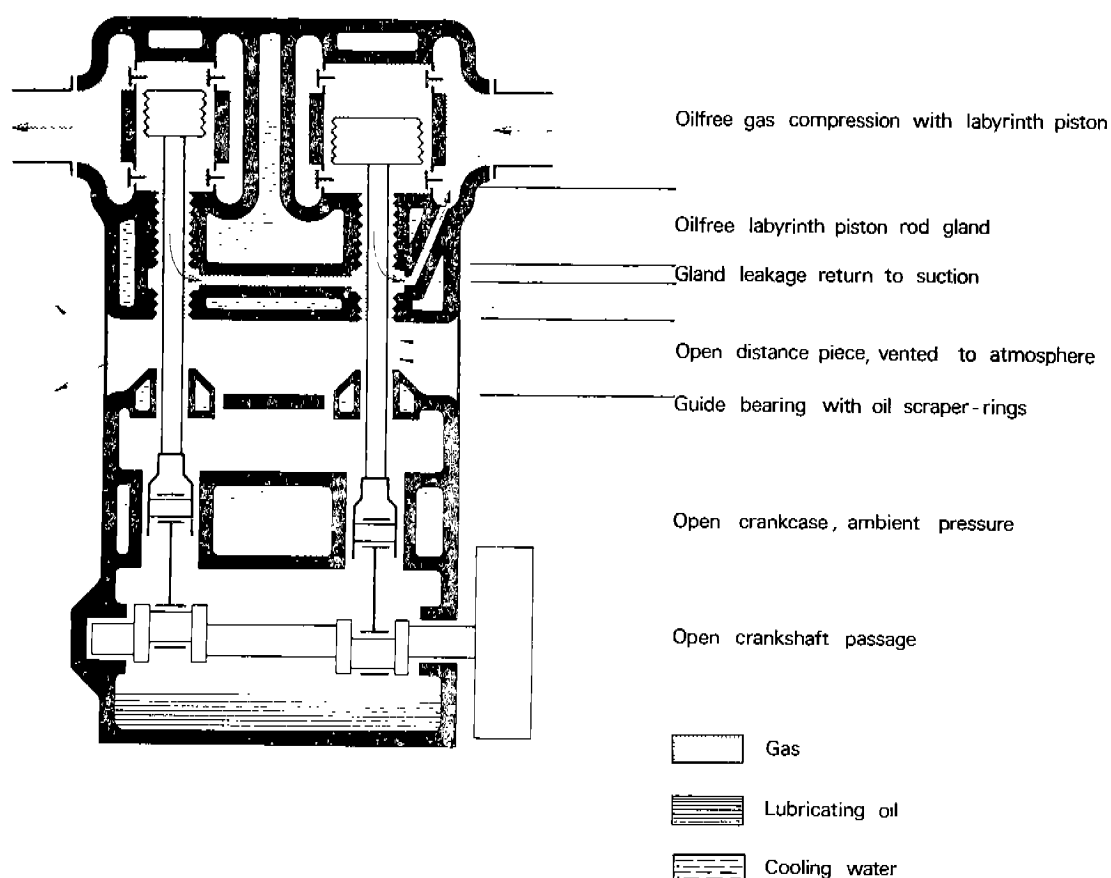


Fig. 8 Labyrinth piston compressor with open crankcase

Compressor Design with Closed Pressure-Tight Crankcase

As a supplement, a completely closed compressor (Fig.9) with a pressure-tight crankcase has been designed mainly to be used in closed or semi-closed, pressurized cycles. The idea of compressing and recycling dry vapors completely free of oil looked very promising, as many problems and inconveniences created by the contamination of the process by oil could be eliminated. The distance piece is now closed and pressurized integrally with the crankcase. Cylinder and distance piece are separated by a labyrinth gland in two subsequent sections with a lantern ring in between, providing the flow back of leakage to suction or other adequate pressure level in the system. In operation at constant pressure conditions, a pressure inside the casing will build up to about the level where gland leakage is recovered. In most cases this is suction and somewhere between vacuum and about 150 psig. Under stopped conditions the system pressure should not exceed 213 psig. For higher figures a special machine design is available.

For these requirements the crankcase is made of one casting. All inspection openings and hand holes are circular; static sealings are of the O-ring type. The only inevitable opening to the outside, which is the penetration of the crankshaft, must be sealed hermetically in the stopped and running state. Excellent results are obtained with a double-sided seal (Fig.10) immersed in an internal oil bath. The half facing the inside prevents the sealing oil from draining back to the sump; the outside half closes against the atmosphere. The two seals are spread against each other by springs. In operation the sealing oil is supplied by the internal lube oil pump.

A closed pressurized compressor frame contains gas or vapors in contact with lub oil. Steps must be taken to prevent this gas from carrying oil into the process. If vented to suction, any variation of process suction pressure level will also affect the pressure in the crankcase. If the suction pressure is decreasing it will result in a flow of gas from the frame to the suction side but no oil should be pulled into the process. The

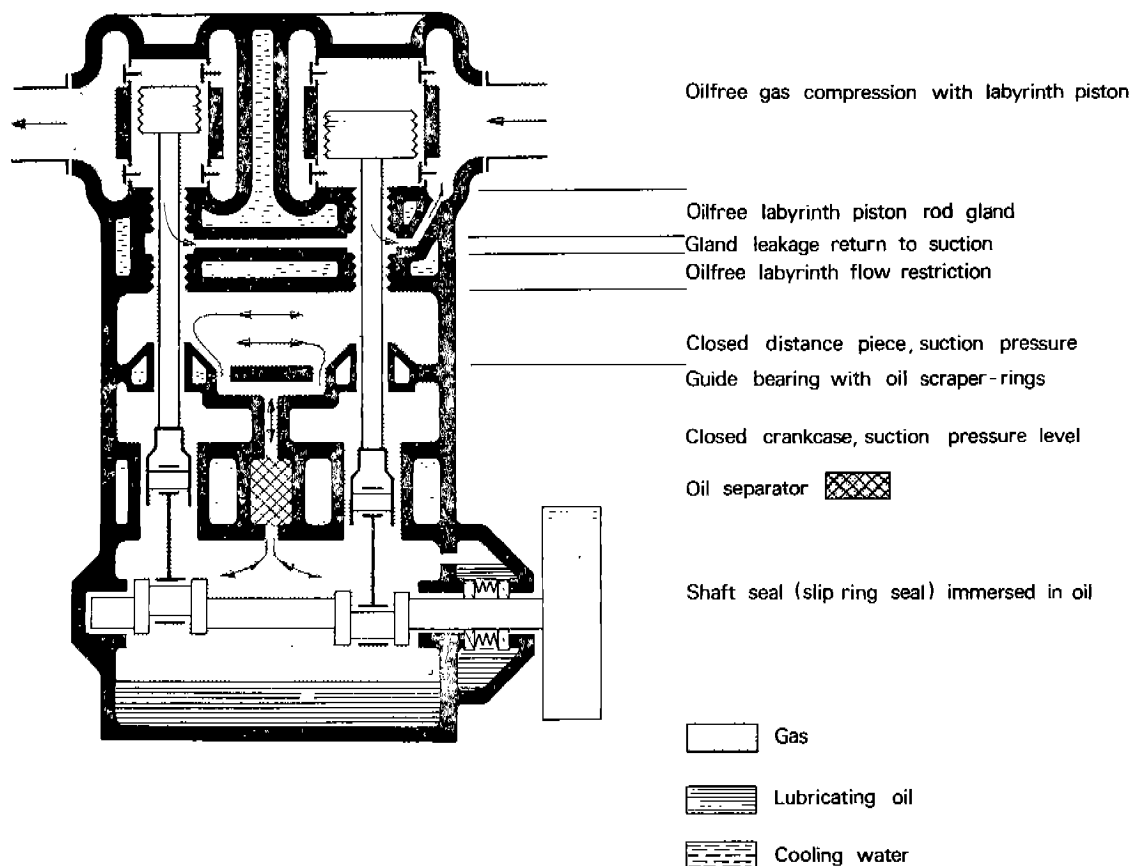


Fig. 9 Labyrinth piston compressor with closed crankcase

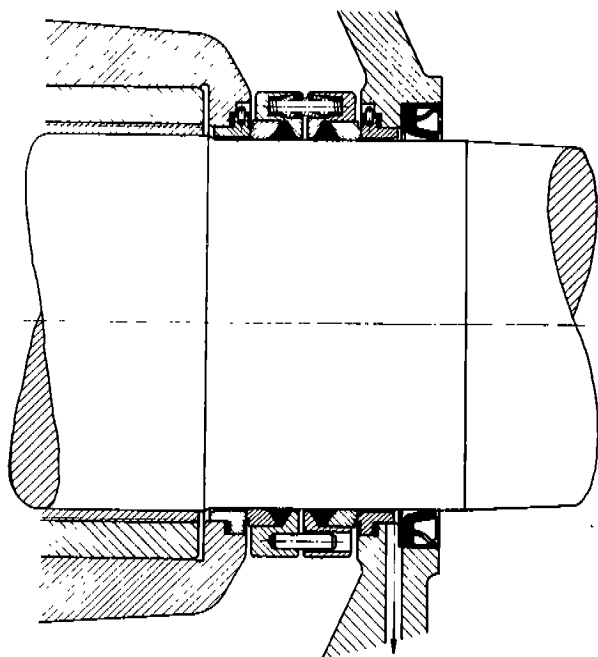


Fig. 10 Double sided crankshaft slip ring seal immersed in internal oil bath

gas expanding from the frame towards the process side is forced to flow through special passages inside the crankcase where a Raschig ring packing in a water-cooled area holds back the oil. The same path is available for the return of oil from the scraper rings to the sump. Before reaching the process side, the gas streaming upwards has first to pass through the restriction of the lower gland section. Thus retarded in its flow it is held back in the distance piece where a second separation of oil traces is taking place by gravity. Practical results have shown that a closed refrigeration cycle remains free of oil even after such a machine has been in operation for years. The hermetically closed reciprocating compressor with an oilfree process part proves very useful in process engineering in general.

CAPACITY CONTROL

There are various systems which may be used to control a reciprocating compressor. Which to prefer depends upon economical as well as technical factors and is influenced by the required control range and sensibility, the process gas, type and size of compressor and driver, maintenance etc. Stopping and starting the driver, speed variation of the driver, blow-off regulation with reduced discharge pressure, bypass regulation, timed suction valves (continuously or in steps), suction throttling, variation of clearance

space etc. are possible.

Stopping and starting as well as speed variation mainly depends on the size and kind of driver. With electric motor drive it is preferred on small compressors with a low power input.

The blow-off regulation is strongly limited by the process gas. For small air compressors it is a very common solution.

One of the most simple capacity controls is the bypass regulation. It can be used for practically all gases and for all compressors and is simple and inexpensive. Multistage compressors may be equipped with a partial bypass over the first stage reducing power input with decreasing mass flow.

Basically all compressors can be equipped with a timed suction valve step regulation (Fig. 11). However, it is realized on smaller sized compressors only with a reasonable number of controlled valves. With this control system cylinder parts are switched off by means of lifter bells blocking-up the valve plates in open position. This results in simultaneous reduction of capacity and power input. The possible steps depend on the number of cylinders per stage and on the piston and cylinder design. The servo-motors moving the lifter bells are actuated by pressurized oil from the compressor lub oil pump. The timed suction valves can be controlled either manually, pneumatically or electrically. They are of such a design that in every case the compressor is started fully or partly unloaded, depending on the number of controlled cylinder parts. For safety reasons we do not recommend timed suction valves for oxygen service.

In practice, not just one but at least two different control systems are combined to provide a wide range of performance and economic potential. The most widely used

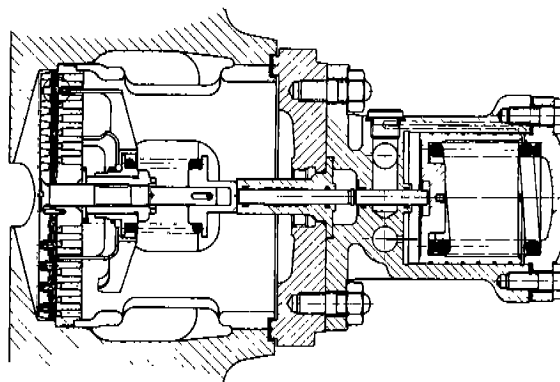


Fig. 11 Oil hydraulic operated timed suction valve for step regulation

combination for smaller sized machines probably is the valve lifter step regulation with bypass first stage and stopping and starting the driver. For larger units, bypass first stage combined with overall bypass regulation and shutting off and on of driver is preferred.

FLOW AND PRESSURE RANGE

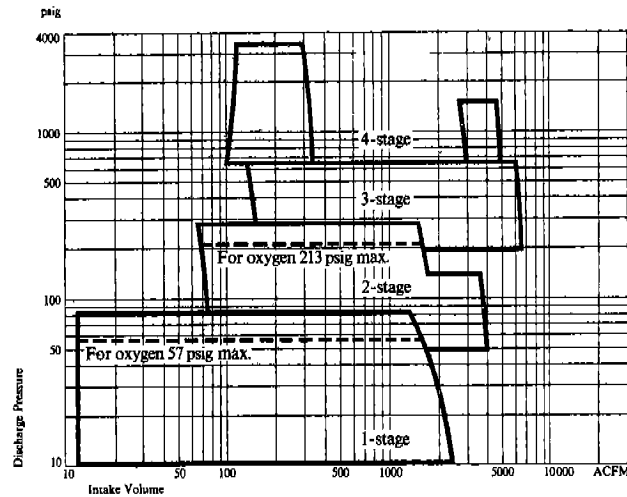


Fig. 12 Flow and pressure range of the standard oilfree labyrinth compressors with open crankcase. Based on air at 14.2 psia and 70°F at intake

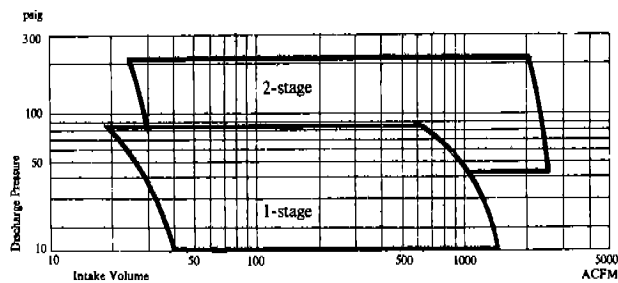


Fig. 13 Flow and pressure range of the standard oilfree labyrinth compressors with closed gas and pressure tight crankcase. Based on air at 14.2 psia and 70°F at intake

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